

## Invariant mass spectra of $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$ decays

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### Abstract

Using  $342 \text{ fb}^{-1}$  of  $e^+e^-$  annihilation data collected with the BABAR detector at the SLAC PEP-II electron-positron asymmetric energy collider operating at a center-of-mass energies near 10.58 GeV, we present the preliminary measurements of the invariant mass distributions of  $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$ ,  $\tau^- \rightarrow K^- \pi^- \pi^+ \nu_\tau$ ,  $\tau^- \rightarrow K^- \pi^- K^+ \nu_\tau$  and  $\tau^- \rightarrow K^- K^- K^+ \nu_\tau$ , where events with  $K_S^0 \rightarrow \pi^+ \pi^-$  decays are excluded.

**Keywords:** Tau, Invariant-Mass

### 1. Introduction

Hadronic  $\tau$  decays provide an opportunity to measure the coupling strength of the weak current to the first and second generations of quarks [1]. They also provide a clean environment to probe low energy QCD and measure fundamental properties of the Standard Model of Particle Physics. Hadronic  $\tau$  decays also play a critical role as a probe to search for new physics at the LHC. With the recent data collected at the B-Factory detectors, significant improvements in our knowledge of the hadronic decay structure can be made, allowing for improved modeling of  $\tau$  decays at the LHC and at the next generation B-Factories.

### 2. Detector, Data Sample and Monte Carlo samples

This analysis employs data collected with the BABAR detector at the PEP-II storage ring which has a centre-of-mass (CM) energy near ( $\sqrt{s}$ ) near 10.58 GeV. At these energies, the cross section is  $\sigma_{e^+e^- \rightarrow \tau^+\tau^-} = (0.919 \pm 0.003) \text{ nb}$  [2]. A detailed description of the BABAR detector and MC Simulation can be found in [3] and [4].

### 3. Invariant Mass Measurements

The analysis of the invariant mass spectra presented in this work is a continuation of branching fraction measurements from [4]. Therefore, the work presented here uses the event selection procedure from [4], but incorporates results from additional studies. For the event selection, a sample of  $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$  decays from  $e^+e^- \rightarrow \tau^+\tau^-$  events is selected by requiring the partner  $\tau^+$  to decay leptonically. Within this sample, each of the  $h^\pm$  mesons is uniquely identified as a charged pion or kaon, and the decay categorized as  $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$ ,  $\tau^- \rightarrow K^- \pi^- \pi^+ \nu_\tau$ ,  $\tau^- \rightarrow K^- \pi^- K^+ \nu_\tau$  or  $\tau^- \rightarrow K^- K^- K^+ \nu_\tau$ , where events with  $K_S^0 \rightarrow \pi^+ \pi^-$  have been excluded. An efficiency correction, initially obtained from MC and corrected using data control samples, is used to correct for efficiency losses from the event selection for each interval in the invariant mass distribution. A detailed description of the selection can be found in [4]. After events are selected the invariant mass distributions are analyzed. First, an arithmetic subtraction of the backgrounds is applied to the invariant mass distributions for each channel. The  $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$  backgrounds between the channels caused by particle misidentification (cross-feed) are normalized to the measured branching fractions in BABAR [4]. Detector effects

are then removed using Bayesian Unfolding [5], which has been trained using the signal MC for each decay mode. The invariant mass distributions are then normalized to unity.

#### 4. Results

The measured and unfolded invariant mass distributions for the  $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$ ,  $\tau^- \rightarrow K^- \pi^- \pi^+ \nu_\tau$ ,  $\tau^- \rightarrow K^- \pi^- K^+ \nu_\tau$  and  $\tau^- \rightarrow K^- K^- K^+ \nu_\tau$  can be seen in Figures 1 to 4. Due to the good resolution of the *BABAR* detector, the unfolding procedure has a minor impact on the invariant mass distributions. This is in contrast to the subtraction of the backgrounds which have the most significant impact on these distributions. The main backgrounds come from the cross-feed from the other  $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$  decays in which a pion or kaon has been misidentified and from events with an extra  $\pi^0$ . The cross-feed backgrounds are estimated to be  $(0.85 \pm 0.01)$  for the  $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$  channel,  $(38.5 \pm 0.2)$  for the  $\tau^- \rightarrow K^- \pi^- \pi^+ \nu_\tau$  channel,  $(2.9 \pm 0.1)$  for the  $\tau^- \rightarrow K^- \pi^- K^+ \nu_\tau$  channel and  $(27.7 \pm 3.0)$  for the  $\tau^- \rightarrow K^- K^- K^+ \nu_\tau$  channel, where the uncertainties are from MC statistics. The background fractions from events with an extra  $\pi^0$  in the candidate samples are estimated to be  $(3.6 \pm 0.3)\%$  from  $\tau^- \rightarrow \pi^- \pi^- \pi^+ \pi^0 \nu$  in  $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$ ,  $(2.3 \pm 0.4)\%$  from  $\tau^- \rightarrow K^- \pi^- \pi^+ \pi^0 \nu$  in  $\tau^- \rightarrow K^- \pi^- \pi^+ \nu_\tau$ ,  $(0.4 \pm 0.1)\%$  from  $\tau^- \rightarrow K^- \pi^- K^+ \pi^0 \nu$  in  $\tau^- \rightarrow K^- \pi^- K^+ \nu_\tau$  and less than 5.0% from  $\tau^- \rightarrow K^- K^- K^+ \pi^0 \nu$  in  $\tau^- \rightarrow K^- K^- K^+ \nu_\tau$ . The non- $\tau$  backgrounds comprise less than 0.5% of the events for each channel.

#### 5. Discussion and Conclusion

In this paper, we have presented unfolded invariant mass spectra using Bayesian unfolding for the decay modes  $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$ ,  $\tau^- \rightarrow K^- \pi^- \pi^+ \nu_\tau$ ,  $\tau^- \rightarrow K^- \pi^- K^+ \nu_\tau$  and  $\tau^- \rightarrow K^- K^- K^+ \nu_\tau$ . Additional studies have been conducted that confirm the *BABAR* branching fraction measurement [4] using control samples to cross-check all the main backgrounds. The  $\tau^- \rightarrow K^- \pi^- \pi^+ \pi^0 \nu_\tau$  and  $\tau^- \rightarrow K^- \pi^- K^+ \pi^0 \nu_\tau$  are also used to validate that the  $K/\pi$  mis-identification rates are consistent within the assigned systematic uncertainties. These invariant mass distributions are essential for determining the strange and non-strange spectral density function and for the extraction of  $|V_{us}|$ . Work is ongoing with T. Przedzinski, P. Roig, O. Shekhovtsova, Z. Was to improve the modeling of these decay modes for the LHC and for the next generation B-Factories using this data.

#### 6. Acknowledgements

We are grateful for the extraordinary contributions of our PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The success of this project also relies critically on the expertise and dedication of the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and the kind hospitality extended to them. This work is supported by the US Department of Energy and National Science Foundation, the Natural Sciences and Engineering Research Council (Canada), the Commissariat à l’Energie Atomique and Institut National de Physique Nucléaire et de Physique des Particules (France), the Bundesministerium für Bildung und Forschung and Deutsche Forschungsgemeinschaft (Germany), the Istituto Nazionale di Fisica Nucleare (Italy), the Foundation for Fundamental Research on Matter (The Netherlands), the Research Council of Norway, the Ministry of Education and Science of the Russian Federation, Ministerio de Ciencia e Innovación (Spain), and the Science and Technology Facilities Council (United Kingdom). Individuals have received support from the Marie-Curie IEF program (European Union) and the A. P. Sloan Foundation (USA).

Additional support for I. M. Nugent was provided by the Alexander von Humboldt Foundation.

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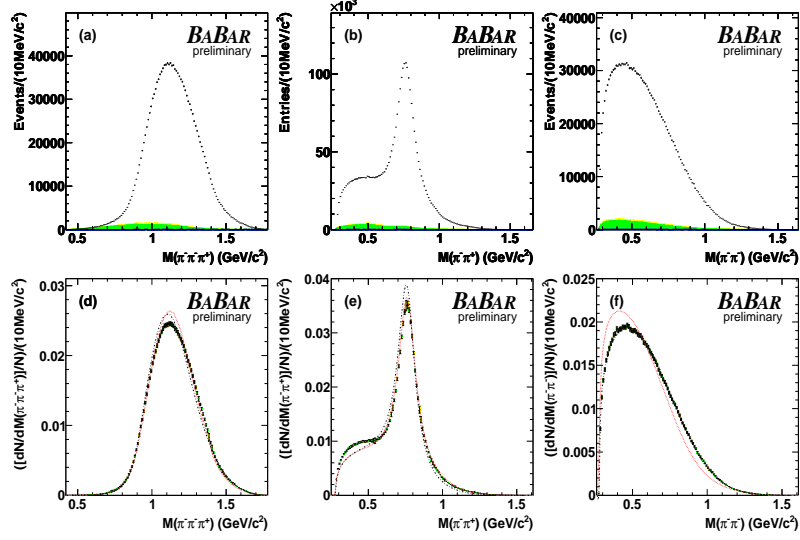


Figure 1: The reconstructed and unfolded invariant mass spectra for the  $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$  channels. The reconstructed invariant mass distributions for (a)  $M(\pi^- \pi^- \pi^+)$ , (b)  $M(\pi^- \pi^+)$  and (c)  $M(\pi^- \pi^-)$  are presented in the first row. In the second row, the (d)  $M(\pi^- \pi^- \pi^+)$ , (e)  $M(\pi^- \pi^+)$  and (f)  $M(\pi^- \pi^-)$  unfolded invariant mass spectra are shown. For the reconstructed mass plots, the data is represented by the points with the error bars representing the statistical uncertainty. The blue (dark) histogram represents the non- $\tau$  background MC, the green (medium dark) histogram represents the  $\tau$  backgrounds excluding the  $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$  cross-feed which are represented by the yellow (light) histogram. For the unfolded mass plots, the data is represented by the points with the inner error bars (green) representing the statistical uncertainty and the outer error bars (yellow) representing the statistical and systematic uncertainties added in quadrature. The integral of the unfolded distribution has been normalized to 1. The black dashed line is the generator level MC distribution used in the BABAR simulation. The red dotted line is the CLEO tune for Tauo1a 2.8 [6].

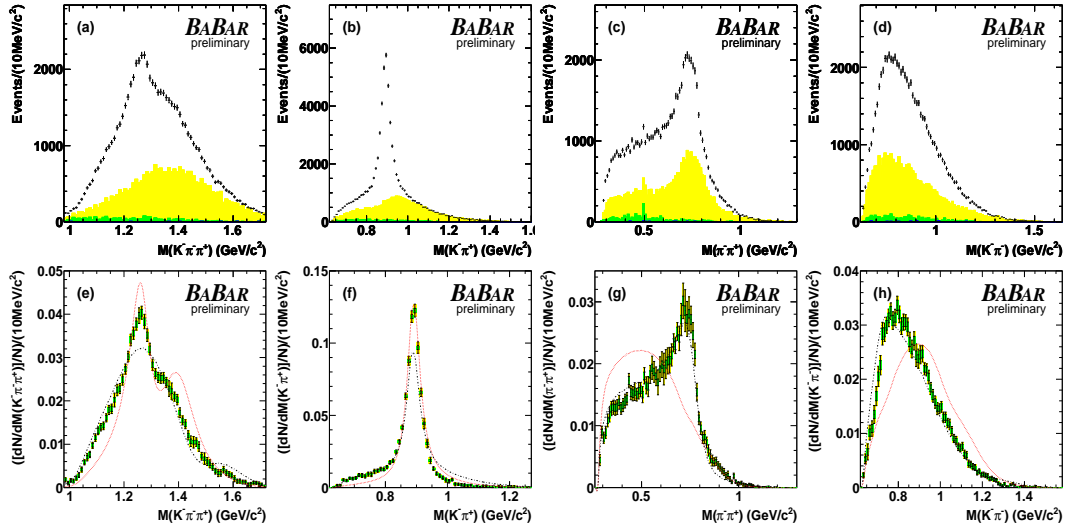


Figure 2: The reconstructed and unfolded invariant mass spectra for the  $\tau^- \rightarrow K^- \pi^- \pi^+ \nu_\tau$  channels. The reconstructed invariant mass distributions for (a)  $M(K^- \pi^- \pi^+)$ , (b)  $M(K^- \pi^+)$ , (c)  $M(\pi^- \pi^+)$  and (d)  $M(K^- \pi^-)$  are presented in the first row. In the second row, the (e)  $M(K^- \pi^- \pi^+)$ , (f)  $M(K^- \pi^+)$ , (g)  $M(\pi^- \pi^+)$  and (h)  $M(K^- \pi^-)$  unfolded invariant mass spectra are shown. For the reconstructed mass plots, the data is represented by the points with the error bars representing the statistical uncertainty. The blue (dark) histogram represents the non- $\tau$  background MC, the green (medium dark) histogram represents the  $\tau$  backgrounds excluding the  $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$  cross-feed which are represented by the yellow (light) histogram. For the unfolded mass plots, the data is represented by the points with the inner error bars (green) representing the statistical uncertainty and the outer error bars (yellow) representing the statistical and systematic uncertainties added in quadrature. The integral of the unfolded distribution has been normalized to 1. The black dashed line is the generator level MC distribution used in the BABAR simulation. The red dotted line is the CLEO tune for Tauo1a 2.8 [6].

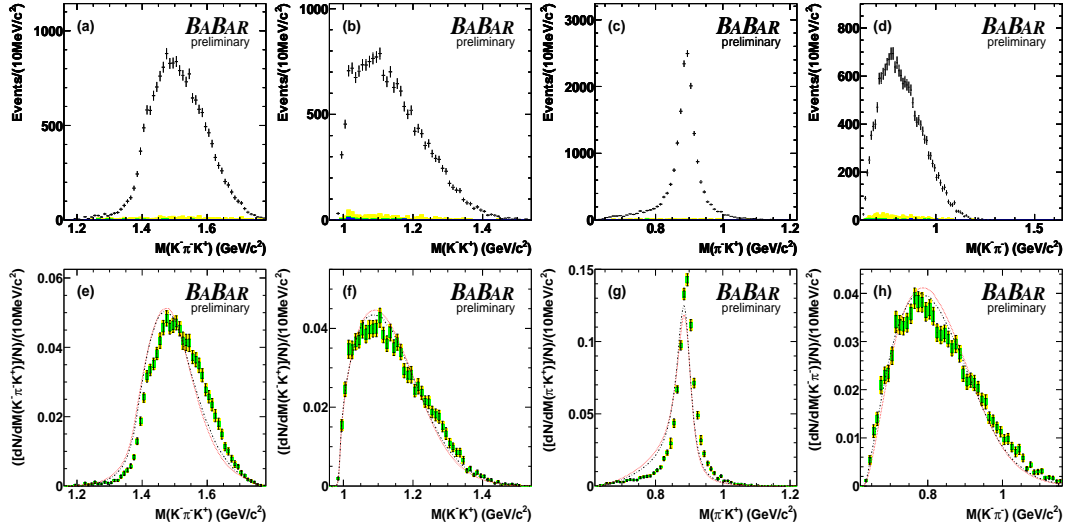


Figure 3: The reconstructed and unfolded invariant mass spectra for the  $\tau^- \rightarrow K^- \pi^- K^+ \nu_\tau$  channels. The reconstructed invariant mass distributions for (a)  $M(K^- \pi^- K^+)$ , (b)  $M(K^- K^+)$ , (c)  $M(\pi^- K^+)$  and (d)  $M(K^- \pi^-)$  are presented in the first row. In the second row, the (e)  $M(K^- \pi^- K^+)$ , (f)  $M(K^- K^+)$ , (g)  $M(\pi^- K^+)$  and (h)  $M(K^- \pi^-)$  unfolded invariant mass spectra are shown. For the reconstructed mass plots, the data is represented by the points with the error bars representing the statistical uncertainty. The blue (dark) histogram represents the non- $\tau$  background MC, the green (medium dark) histogram represents the  $\tau$  backgrounds excluding the  $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$  cross-feed which are represented by the yellow (light) histogram. For the unfolded mass plots, the data is represented by the points with the inner error bars (green) representing the statistical uncertainty and the outer error bars (yellow) representing the statistical and systematic uncertainties added in quadrature. The integral of the unfolded distribution has been normalized to 1. The black dashed line is the generator level MC distribution used in the BABAR simulation. The red dotted line is the CLEO tune for Tau01a 2.8 [6].

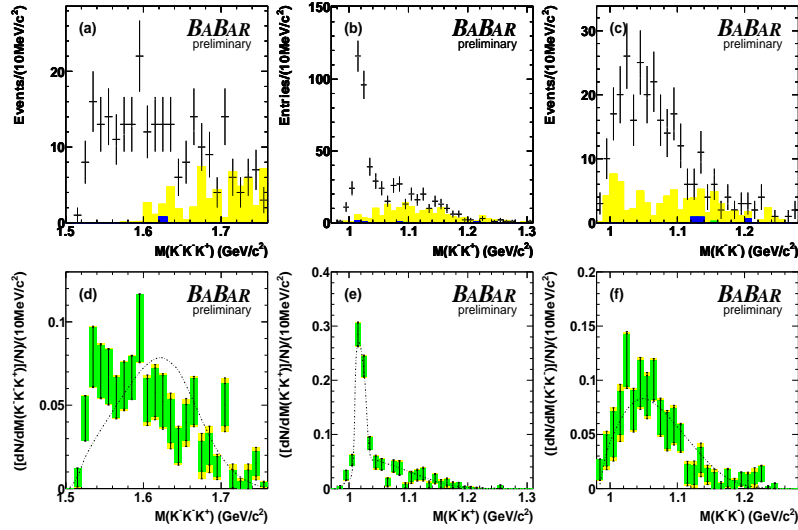


Figure 4: The reconstructed and unfolded invariant mass spectra for the  $\tau^- \rightarrow K^- K^- K^+ \nu_\tau$  channels. The reconstructed invariant mass distributions for (a)  $M(K^- K^- K^+)$ , (b)  $M(K^- K^+)$  and (c)  $M(K^- K^-)$  are presented in the first row. In the second row, the (d)  $M(K^- K^- K^+)$ , (e)  $M(K^- K^+)$  and (f)  $M(K^- K^-)$  unfolded invariant mass spectra are shown. For the reconstructed mass plots, the data is represented by the points with the error bars representing the statistical uncertainty. The blue (dark) histogram represents the non- $\tau$  background MC, the green (medium dark) histogram represents the  $\tau$  backgrounds excluding the  $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$  cross-feed which are represented by the yellow (light) histogram. For the unfolded mass plots, the data is represented by the points with the inner error bars (green) representing the statistical uncertainty and the outer error bars (yellow) representing the statistical and systematic uncertainties added in quadrature. The integral of the unfolded distribution has been normalized to 1. The black dashed line is the generator level MC distribution used in the BABAR simulation which assumes that  $\tau^- \rightarrow K^- K^- K^+ \nu_\tau$  decays entirely through  $\tau^- \rightarrow \phi K^- \nu_\tau$ .